## Report to the 21th Meeting of CCTF

# Research Activities on Time and Frequency National Metrology Institute of Japan (NMIJ)/AIST

The National Metrology Institute of Japan (NMIJ) is responsible for almost of all physical and chemical standards and for related technologies in Japan. The Time Standards Group and the Frequency Measurement Group of NMIJ are in charge of time and frequency metrology. We describe the recent activities of these two groups in this report.

## 1. Cs atomic fountain frequency standards

As for our first cesium fountain NMIJ-F1 with an uncertainty of $4\times10^{-15}$, the operation has stopped since the huge earthquake in March 2011. Now we are pending its restart due to lack of fund and human resource. The apparatus of our optically-pumped cesium-beam frequency standard, NRLM-4, was discarded. The apparatus of NMIJ-F1 and the laser source for NMIJ-F1 and F2 were moved to the place where NRLM-4 had been located.

Our second cesium fountain, NMIJ-F2, is under construction. The microwave power dependence shift was reduced by turning off the Ramsey interrogation microwave with an rf switch after the second interrogation, and evaluated to be $(1.0\pm1.1)\times 10^{-16}$. Including this, type B uncertainty due to the major effects was evaluated to be $7\times10^{-16}$. We are trying to confirm the uncertainty due to minor effects to be negligible and to conduct frequency comparison with TAI.

## 2. Cryogenic sapphire oscillators

Two liquid-helium-cooled cryogenic sapphire-resonator oscillators (CSOs), have been modified to operate using cryo-refrigerators and low-vibration cryostats [1]. The Allan deviation of the first cryo-refrigerator-cooled CSO (cryoCSO) was evaluated to be better than $2\times10^{-15}$ for averaging times of 1 s to 30 000 s, which is better than that of the original liquid helium cooled CSO. It has been used with our cesium fountain, NMIJ-F2, which has achieved a nearly quantum-projection-noise-limited frequency stability. The Allan deviation of the second cryoCSO is better than $4\times10^{-15}$ from 1 s to 6 000 s averaging time.

## 3. Time keeping

There are four H-maser standards and three Cs atomic clocks to maintain UTC(NMIJ). Now we are reporting the data of four H-masers and three Cs clocks to BIPM every month. The source oscillator of UTC(NMIJ) is one of the H-masers since 2006. We have introduced a new maser in the fiscal year 2012. Temperature controlled chambers for clocks are working well to keep the inside temperature within 0.2 K of peak-to-peak variation. Frequency steering using AOG has been done appropriately. These activities resulted in generating stable UTC(NMIJ) within ±20 ns to UTC for 3 years between 2015 and 2017 (almost less than ±10 ns). Relative frequency of UTC(NMIJ) to UTC has been kept within $\pm 3.0\times 10^{-14}$ (almost less than $\pm 1.0\times 10^{-14}$) between 2015 and 2017 as shown in Fig. 1.

## 4. Time and frequency transfer

We use GPS PPP method for the international time and frequency transfer to contribute to the TAI using Z12-T. NMIJ has been participating in a rapid UTC (UTCr) since January 2012.

## 5. Calibration service

NMIJ provides frequency calibration services for both in-house and remote facilities. The CMC is $5\times 10^{-14}$ for in-house and $1.1\times 10^{-13}$ (Baseline: 50 km), $1.4\times 10^{-13}$ (Baseline: 500 km) and $4.9\times 10^{-13}$ (Baseline: 1600 km) for remote calibration, respectively. As remote frequency calibration service, traditional GPS common-view method is used in the system. It consists of a user equipment, a data transfer protocol, and a data processing system. Now we are offering the service to 20 remote users.

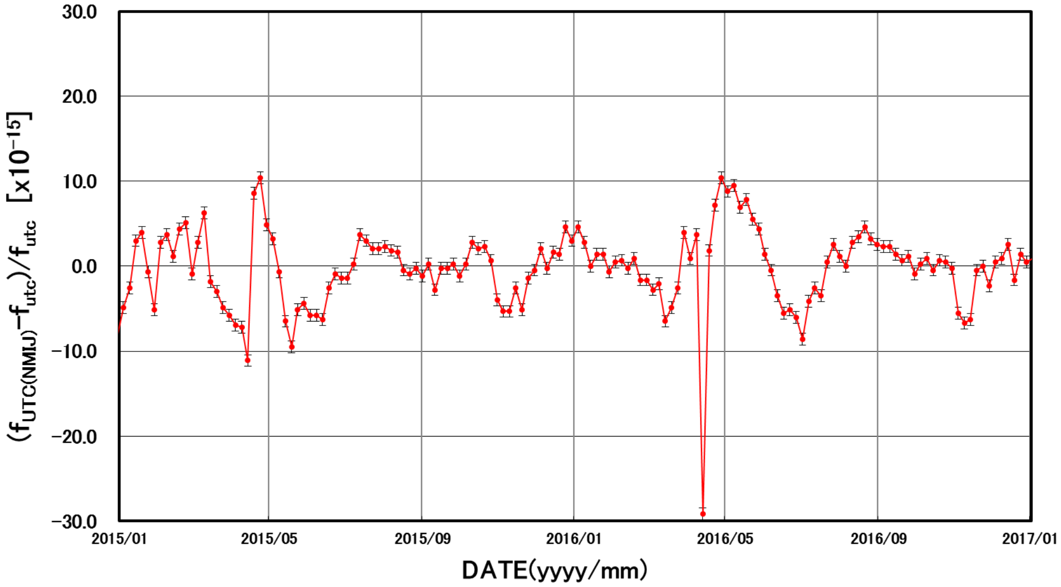

Fig. 1 Relative frequency offset of UTC(NMIJ) to UTC between 2015 and 2017.

## 6. Optical lattice clocks

We are developing a dual optical lattice clock system of strontium and ytterbium. Both atomic species have been successfully laser-cooled and loaded to optical lattices at the same location in the vacuum chamber [2].

We have started developing our third optical lattice clock, which is aimed for continuous long-term operation. For the new clock system, we have newly developed a compact and robust 399-nm light source resonant on $^1S_0$-$^1P_1$ transition in ytterbium using a periodically poled lithium niobate waveguide [3]. The output of 25 mW was obtained for 380mW of the fundamental power. We also demonstrated that the output can be used as a seed light for injection locking and amplified up to 200 mW. The amplified power is used for 1st stage cooling of ytterbium.

## 7. Frequency comb

For optical lattice clocks, home-made fiber-based frequency combs have been used to measure the absolute frequency and the ratio of the clocks, to stabilize the cooling lasers, and to transfer a linewidth of an ultra-stable laser to the clock lasers. Recently, we are mainly conducting research and development of dual-comb spectroscopy and its applications[4, 5], astro-comb, and novel method to broaden[6] or stabilize[7, 8] combs.

## References

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